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14. ABSTRACT

In this period of performance (April 1, 2000 - March 31, 2003), progress has been made. The highlights of these results are reported. This final reports consists of two parts: (I) Solar Interplanetary Coupling Study and (II) Interplanetary and Ionospheric Coupling Study. We will describe our achievements for this grant in the following:

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Summary of Progress: April 1, 2000 – March 31, 2003

In this period of performance (April 1, 2000 – March 31, 2003), progress has been made. The highlights of these results are listed below. This final reports consists of two parts: (I Solar Interplanetary Coupling Study and (II) Interplanetary and Ionospheric Coupling Study. We will describe our achievements for this grant in the following:

I. Solar Interplanetary Coupling Studies:

To understand the physics of solar eruption effects on Earth's environment, the first step is to investigate the fundamental physical mechanisms of the solar eruptive features which will propagate to the Earth's environment. In this section, we will summarize the major findings during the period of performance as follows:

(1) CME(s) Initiation Processes

Using two types of observed CME events (i.e. 3 Jan 1998 and 22 June 1998) and our streamer and flux-rope model, we reveal two CME initiation processes: (a) Streamer destabilization due to increase of filament currents, via increase of the axial field of the flux-rope, which leads to the generation of additional Lorentz force to destabilize the streamer. Subsequently, a CME is launched; and (b) Photospheric shear-induced loss-of-equilibrium of a streamer and flux-rope system is demonstrated to be capable of launching a CME. Detailed results for these two cases are published in *JASTP* 62, 1498-1998, 2000a as listed on Page C-3.

(2) Identification of a Physical Mechanism for the Formation of SOHO/LASCO Observed Plasma Blobs in the Sun's Streamer Belt.

Recent observations obtained by the Large Angle Spectrometric Coronagraph (LASCO) on the Solar and Heliospheric Observation (SOHO) reveal the motion of density enhancements in the coronal belt (Sheeley, et al. 1997, *Ap. J.*, 484, 472; Wang et al. 1998, *Ap. J.*, 498, L165) which are defined as *plasma blobs*. These plasma blobs originate at about 3-4 R_s from Sun-center as radially elongated structures above the cusps of helmet streamers. The plasma blobs move radially outward, maintaining constant angular spans, and have a speed of ~200 km s^{-1} in the outer portion of the LASCO/C3 field of view (~ 30 R_s). In order to understand the physical mechanism which causes this phenomenon, we have constructed a resistive MHD model to illustrate the physical process which reveals that these plasma blobs are formed due to the magnetic reconnection of multi-loops within a global equatorial streamer. A paper about these results is published in *Astrophys. J.* 545, 1101-1115, 2000b, as listed below.

(3) Identification of the Observed EIT waves

Recently SOHO/EIT observations discovered multiple cases of a global large amplitude wave propagating across the solar disk (Thompson et al. 1998). These waves appear to be similar to those observed in the H-alpha in the chromosphere and are known as "Moreton Waves" associated with large solar flares (Moreton 1960, 1964). To search for an understanding of the physical characteristics of these newly observed EIT waves, we have successfully

identified a particularly well-documented case of these observed EIT waves to be the fast mode MHD wave dominated by the acoustic model (i.e. magnetosonic wave) (Wu et al. 2001b.) We believe that our self-consistent 3D MHD numerical simulation procedure holds great potential for a rigorous physically-based study of CME initiation and propagation.

(4) Modeling of Successive CMEs

Recently, we accomplished modifying our present streamer and flux-rope model to include bi-modal solar wind for the investigation of CME interaction with other CMEs. The preliminary results were presented at the recent IAU Colloquium 188 in Santorini, Greece. These results showed that CME interaction (popularly known as cannibalization) is caused by magnetic reconnection. Successive CMEs collision-induced shocks have a direct relationship with metric Type II radio emissions.

A total of eleven papers are published, three papers are in or have been submitted for publication during the grant period of performance.

II. Solar Interplanetary Coupling Studies:

To understand the physics of solar eruptive effect of the Earth's environment, the first step is to investigate the fundamental physical mechanisms of the solar eruptive features which will propagate to the Earth's environment. In this section, we will summarize the major findings during the period of performance as follows:

(1) Coupling functions

We investigated coupling between the solar wind and the Earth's ionosphere by looking for statistical correlations between the solar wind parameters that can be modeled by our MHD code (density, velocity, IMF) and the magnetic activity indices used as input to our ionospheric models (principally a_p). The purpose of this study was to look for circumstances under which a_p can be expected to be well correlated with solar wind parameters and to see if these circumstances can be predicted in advance.

Solar wind parameters from the Wind Magnetic Fields Investigation (MFI) and Solar Wind Experiment (SWE) Key Parameter data sets were selected for 26 impulsive pressure pulse events from 1997 and 1998. These events were originally selected for studies of auroral responses to interplanetary pressure pulses and typically contain at least one impulsive change in solar wind parameters for each day of data. For each event, data from the previous and following days were also selected to provide a 3-day period centered on each event. Events for which the Wind spacecraft was within 20 Re of Earth were excluded from the analysis. A total of 63 days of data were analyzed.

Thirteen solar wind coupling functions (SWCF) were calculated from solar wind parameter (Table 1). (The Akasofu epsilon parameter, SWC0, in Table 1 is the same, except for a multiplicative factor, as SWC9.) These functions represent most of the analytical functions that have been used as proxies of solar wind-magnetosphere coupling. The SWCF, therefore, can be expected to offer the best correlations with a_p.

Table 1. Solar wind coupling functions.

ID	Function
SWC0	Akasofu Epsilon
SWC1	B_z
SWC2	$V B_z$
SWC3	$V B_T$
SWC4	$V^2 B_z$
SWC5	$V B_z^2$
SWC6	$V B_T \sin(\theta_c/2)$
SWC7	$V B_T \sin^2(\theta_c/2)$
SWC8	$V B_T \sin^4(\theta_c/2)$
SWC9	$V B^2 \sin^4(\theta_c/2)$
SWC10	$P^{1/2} V B_z$
SWC11	$P^{1/3} B_T^2 \sin^4(\theta_c/2)$
SWC12	$P^{1/6} B_T \sin^4(\theta_c/2)$
	$B_T \equiv \sqrt{(B_y^2 + B_z^2)}$

Solar wind propagation delays were calculated for each event based on the Wind spacecraft GSM x-position and the solar wind x-velocity. A systematic delay of 1 hour was added as well (based on lag-delay correlation analysis). The solar wind data, with these delays, was then used to calculate each of the coupling functions from Table 2 and binned into 3-hour intervals. These functions were compared with ap values from the same 3-hour periods by calculating the Pearson's linear correlation coefficient, r(SWC, ap). Each day was analyzed independently, without attempting to compare data from contiguous days. The goal was to determine how well the indices are correlated with changes in the coupling functions, to determine if possible delays usually associated with magnetospheric loading processes are evident in the index comparisons, and to assess the practicality of estimating ionospheric response to solar wind disturbances based on calculated solar wind parameters. Particular attention was given to instantaneous versus aggregate correlations since the ultimate goal is to accurately model ionospheric response to individual events.

As expected, each of the coupling functions showed good statistical correlations with ap over the full event set. However, no single function correlated well with all the events, though there were days for which all the functions were well correlated not only with ap, but with each other as well. Furthermore, the opposite did not appear to true. In other words, there were few cases in which all the coupling functions were poorly correlated with ap.

To visualize this effect, the mean of the correlation coefficients with a_p for all SWCF, $\langle r_{ext} \rangle$, was calculated for each event. In the discussion below this will be referred to as the external correlation. To estimate the degree of agreement between the different SWCF, hereinafter referred to as the internal correlation, the correlation coefficient between the Akasofu epsilon parameter (SWC0) and all the other SWCF, r_{int}, was calculated. (The comparison between SWC0 and SWC9 was not included since they have the same functional dependence.) Another measure of the internal correlation of the collection of coupling functions is the standard

deviation of the data set about its mean. This was also calculated for the internal correlation, $\sigma(r_{int})$.

These values are shown in Figure 1. Recall that the events are selected in 3-day intervals with two adjacent 3-day intervals (events 9-14). Therefore changes between adjacent events in Figure 1 are not necessarily between adjacent days. Visual examination of Figure 1 reveals several instances of good correlation between $<r_{ext}>$ and r_{int}. Examples are marked by vertical arrows in the figure. For each of these events, the standard deviation of the internal correlation $\sigma(r_{int})$ is also seen to be small. Both of these findings are consistent with the premise that good agreement within the SWCF implies good correlation with a_p. Not all events, of course, show such clear agreement. See, for example, the events marked with stars in Figure 1.

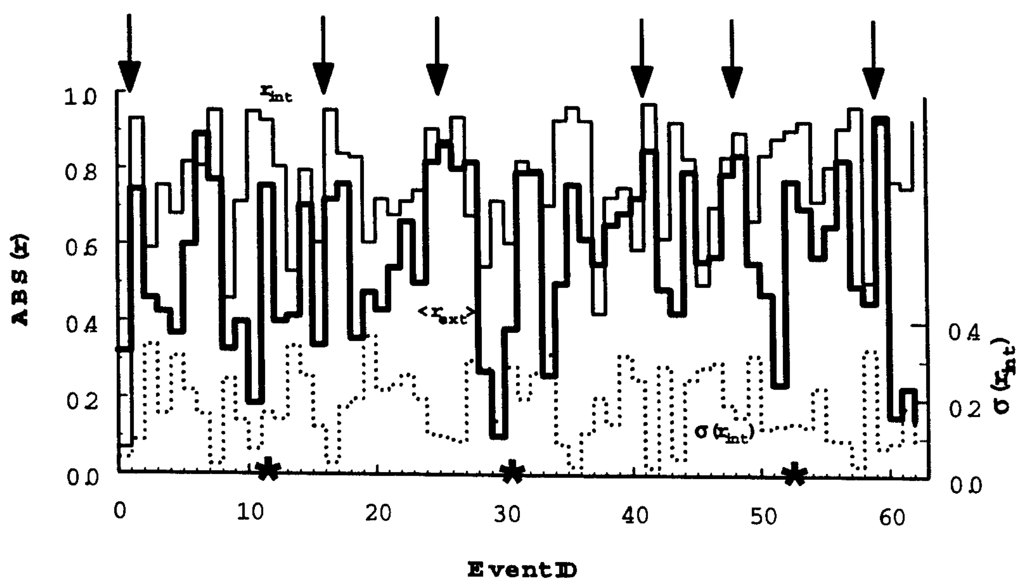

Figure 1. Mean external correlation coefficient $<r_{ext}>$, internal correlation coefficient r_{int}, and standard deviation of internal correlation $\sigma(r_{int})$. Arrows denote examples of good agreement and stars show examples of poor agreement.

In summary, correlations between solar wind coupling functions calculated from solar

wind parameters and the magnetic index ap were examined for 63 events. All the SWCF agreed well with ap in a statistical sense, but no single function correlated well with every event. However, it was found that agreement within the collection of SWCF generally indicated good correlation with ap. This finding is statistically significant and is not due to improved coupling for events with higher ap values.

This study thus indicates that different coupling functions should be simultaneously polled for their correlation with a_p. In the present case, when the SWCF agree with each other it can be assumed that they present an accurate representation of the changes in a_p. When they disagree, nothing can be said since different coupling functions may exhibit widely varying correlations with a_p for the same event. Nevertheless, such polling could form the basis of determining predictive events on a real time basis.

This study was presented at the 2000 Fall Meeting of the AGU [Germany, G.A., S.T. Wu, P.G. Richards, A.-H. Wang, T.X. Zhang, X.Y. Wu, and M. Cuntz, Correlation between solar wind and activity indices: Is it sufficient to estimate ionospheric response to solar disturbances?, *EOS Trans. AGU, Fall Meet. Suppl.*, *81*(48), F1049, 2000]. It was submitted for publication in Geophys. Res. Lett., but was rejected on disagreements over the statistical analysis. Nonetheless, we feel the study's conclusion, namely that different coupling functions should be simultaneously polled for their correlation with a_p, is a significant one and are continuing to study this.

(2) New models

We obtained agreement from Drs. Tim Killeen and Alan Burns to use a copy of their 'portable', i.e. small-scale, general circulation model (TING) in this study. This would greatly augment the FLIP model we are currently using, since FLIP is limited to a single field line while the TING model is a 2-D simulation. The TING model requires inputs beyond a_p used in FLIP (principally AE, Dst, and cross-cap potential), which would require us to extend our solar wind correlation study to include these additional parameters.

We contacted Dr. Alan Burns and subsequently downloaded a copy of the TING model. Unfortunately, the model had not previously been distributed and there were significant problems and questions about running it on our computers. However, we were eventually able to get it running. But since it was developed on a UNIX workstation, we were forced to run it on a similar station here. The Unix computer we initially installed the TING model on was a NASA computer not affiliated with this project. The NASA system administrators expressed an unwillingness to let us use their computer for non-NASA projects. In addition, NASA security protocols prevented us from using non-US citizens to help with the code development. Therefore, we had to remove the model from the NASA workstation.

Attempts to compile the TING model on our native VMS platforms failed and we were unable to get adequate support from the model's authors to overcome this problem. In short, despite significant effort, we were unable to use the TING model to support this research.

Nonetheless, this was a useful exercise. We established working collaborations with Dr. Burns and his team. Consequently, we are currently seeking funding opportunities to work together on this. In addition, this highlighted the need for an in-house global modeling capability. Therefore we are preparing proposals to extend the 1-D FLIP model to a more global representation.

(3) Ionospheric modeling

We did a number of sensitivity studies in which we examined the response of select ionospheric parameters to changes in the input model parameters that could be affected by the solar wind. For example, we looked at changes in hmF_2 and nmF_2 as a function of changes in a_p. This was further binned by local time and geographical location. We also compared our modeling with observations when possible. However, the local modeling we were doing (single flux tube) did not include global features such as ionospheric storm response. Hence we were unable to sufficiently isolate the 'normal' ionospheric response to solar wind changes from more larger, more complex storm-time responses. The fact that the storm-time response varies with time, local time, and geographic location underscored the importance of developing a global ionospheric modeling capability.

In a final study, we attempted to scan the NGDC Ionospheric Digital Database of ground measurements to create a long-term perspective of ionospheric response to storm-time conditions. This offered the promise of performing statistical analysis that could 'smooth out' the effects of individual storms. Unfortunately, we have been unable to finish this study in the time available. We hope to find an opportunity to complete this study in the future.

Personnel:

	Name	Degree	Discipline	Involvement
In House Employees	S. T. Wu	Ph.D.	Aero. Engr. Sci.	1/10
	A. H. Wang	Ph.D.	Physics	1/2
	P. Richards	Ph.D.	Space Physics	1/10
	G. Germany	Ph.D.	Aeronomy	1/10
	A. Song	Ph.D.	Space Physics	1/2
	T. Zhang	Ph.D.	Physics	1/7
Subcontractors/Visitors-	Mu-Tao Song	Ph.D.	Physics	1/12

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(b) Accepted/Submitted for Publication

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